Integrated Active Filters using low gain modules

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***Abstract*—New integrated filters in CMOS technology are presented which use current mirror based amplifiers to create low gain modules as structural active blocks. The simplest current amplifiers are purposely chosen. Wave techniques are used for obtaining high reliability and low sensitivity filters of any type. The derived filters are modular, simple in structure and easy to design. Examples in simulation level are given.**

***Index Terms*—active filters, CMOS integrated filters, Organic analog circuits.**

I. Introduction

In the past, various methods and techniques have been developed for obtaining linear active filters. To this end the criteria for selecting the active devices and the design method are related to the application under consideration. However, in every case, reliability and a low sensitivity performance of the circuits derived remains an intended target. This requirement is of great importance especially in integrated circuit design since component trimming after fabrication is not possible. It is well known that passive LC filters show a very low sensitivity property in the pass-band [1]. It has been also shown that in many cases the simulation of passive circuits using active components results in structures that obtain low sensitivity. The most competing methods for obtaining active filters that simulate LC passive prototype are the Leapfrog (functional simulation) method and the Generalized Impedance Converters (GIC or topological simulation) method [1]. The Wave Active Filter method (WAF), which initially was derived by using scattering parameters description, can be regarded as a more flexible GIC method leading in a variety of solutions. This method leads to signal flow graphs representing the passive filter that incorporate lossy paths in contrast with leapfrog type filters where lossless integrators are needed. In the past many structures of WAFs either in the voltage or the current domain have been published [2]-[4] and also, linear and nonlinear solutions have been given [5]. Differential mode circuits based on WAF have also been presented in [6]. An interesting feature of WAFs is that they are incorporating active modules of maximum gain two. This feature allows operation of the circuits at higher frequencies. Especially in the current domain one can expect operation near to the f_T of the transistors used. A number of papers have been published using low gain current amplifiers [7]-[10]. The proposed structures, however, are relying on lossless integrators. WAFs of any type are relying on lossy integrators, that is, on first order low and high pass structures offering high reliability. These structures are obtained in this paper by using low gain amplifiers that incorporate a minimum number of transistors. For instance, a gain one or two current amplifier (inverter) can be obtained by using only four transistors. Amplifiers of this type can operate even by using of low quality transistors. This fact allows us of expecting that such amplifiers could operate also by using organic transistors [11]-[14]. The fabrication of high quality organic complementary transistors on the same material has not been accomplished satisfactorily yet, and is still under development. Therefore, only a few attempts for making simple circuits have been published until now, especially for analog blocks, [14]. Although analog organic circuits are still in their infancy we are planning, in a next approach, to investigate developing analog organic filters using the proposed structures in this paper.

II. On The Design Method

Without any loss of generality we restrict our approach on the simulation of low-pass LC passive prototype filters. Any type and order of passive filter can be simulated by following a similar approach. Let us consider the low-pass third order passive filter shown in Fig.1a which is going to be simulated. Applying the wave method as it is described in the references given, the signal flow graph of the filter, is taken as it is shown in Fig.1b. On this graph s_{ij} are the scattering parameters of a grounded capacitor which is seen as a two port network. These parameters represent low-pass and high-pass transfer functions of first order. This way the input signal is traveling towards the *OUTPUT 2* by following low-pass paths and reflected back to *OUTPUT 1* by following high-pass paths. The resulted two outputs are power complementary to each other. This means that, if the two transfer functions are denoted by,

$$H_2(s) = \frac{I_2(s)}{I_i(s)} \text{ and } H_1(s) = \frac{I_1(s)}{I_i(s)} \tag{1}$$

then,

$$H_1^2(jw) + H_2^2(jw) = 1 \tag{2}$$

where s is the complex frequency.

In other words, if $H_2(s)$ is low-pass function then $H_1(s)$ is its power complementary function. The two functions are crossed at the -3dB point.

The graph in Fig.1b can be simulated by the circuit whose topology is shown in Fig.1c. This circuit consists of three similar modules each one of which represent the wave equivalent circuit of a grounded capacitor. The modules are interconnected either directly or through current inverters. However these current inverters can be incorporated within the modules.

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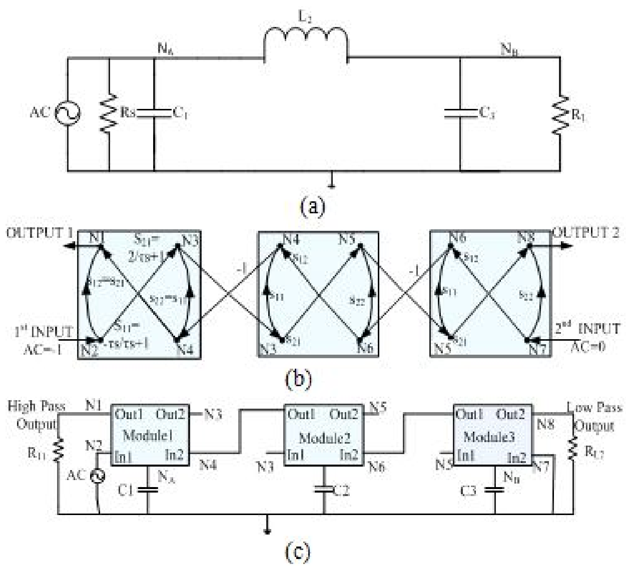


Figure1: a) Third order filter with passive components
b) Signal Flow Graph Figure
c) Third order Butterworth filter with active component

Looking at the topology in Fig.1c, we see that there is one by one correspondence between this topology and the one of the passive circuit. This means that a topological simulation of the LC passive prototype filter has been achieved. Therefore, the active circuit between the nodes N_A and N_B in Fig.1.c represents an active floating inductor. We can make use of this fact for developing filters that contain transmission zeros, as they are elliptic filters, in a very straightforward way.

III. On The Implementation Of The Circuits

As we have already mentioned the topology in Fig.1c consists of three similar modules. These modules can be implemented by the circuit shown in Fig.2. This circuit obtains two outputs, i.e., one low-pass and one high-pass output according to the graph in Fig.1b. The time constant of each block is created by the product R_iC where R_i is the input resistance of the amplifiers. Since the input resistance is bias dependent the time constant of each module can be tuned by the bias current of the current mirrors. Therefore, in cases where tunable filters are required an extra bias circuitry should be added for tuning purposes, [4]. Each one of the blocks in Fig.2 is realized by CMOS current mirror based amplifiers.

The simplest amplifiers of this type are shown in Fig.3a and Fig.3b. In biasing these amplifiers provision has been taken in order that the input and the output nodes to be in the same DC voltage level for simplifying interconnections. In the particular case the DC input and output voltage has been chosen to be 1.5V. It is expected that the amplifier in Fig.3a could operate by using low quality transistors, like the thin film organic transistors, since these can be described by a law similar to the one describing CMOS transistors, [13]. In a first approach we simulated a gain two current amplifier according to specifications taken from [11], [12]. Our simulation results are quite promising.

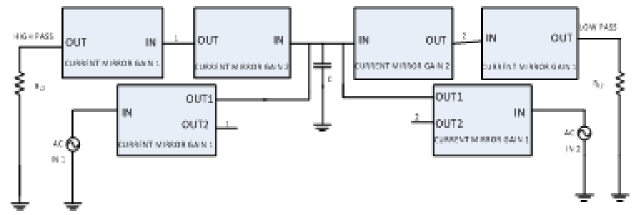
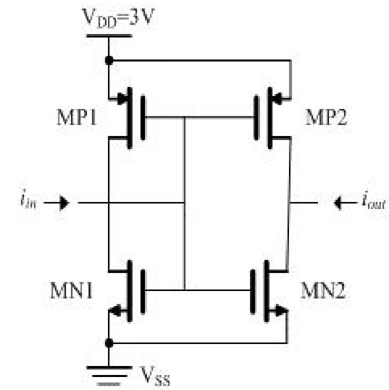
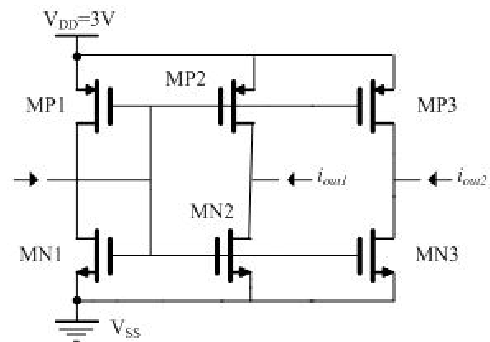


Figure 2. First Order Module



$$\text{For gain one}: \frac{W_{N1}}{L_{N1}}=\frac{1.25}{1},\quad \frac{W_{N2}}{L_{N2}}=\frac{1.35}{1},\quad \frac{W_{P1}}{L_{P1}}=\frac{5}{1},\quad \frac{W_{P2}}{L_{P2}}=\frac{5}{1}$$

(a)



$$\text{For gain two}: \frac{W_{N1}}{L_{N1}}=\frac{1.25}{1},\quad \frac{W_{N2}}{L_{N2}}=\frac{2.65}{1},\quad \frac{W_{P1}}{L_{P1}}=\frac{5}{1},\quad \frac{W_{P2}}{L_{P2}}=\frac{10}{1}$$

(b)

Figure 3: a) Single output current mirror based amplifier-inverter
b) Dual output gain one amplifier

IV. Examples And Discussion

Two third order low-pass filters have been designed and simulated using SPICE and CADENCE tools.

The first circuit whose topology is shown in Fig.1c realizes a Butterworth function. For a cutoff frequency=42KHz the capacitor values are C_1=1n, C_2=2n and C_3=1n. A 0.35μm CMOS technology from AMS has been chosen. The power supply was 3V and the amplifiers were biased at 60μA. In this case the input resistance of the amplifiers was R_i=4KΩ. The output resistance was 54.6KΩ. Although the output resistance does not influences seriously the performance of the circuits a small modification of the aspect ratio of the transistors was applied in order to bring the gain of the current amplifiers in its nominal value. This procedure is especially necessary in

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the case of organic transistors where the output resistance is not quite high. The two simulated responses of the Butterworth filter are shown in Fig.4. As a second example an elliptic filter has been designed. This has been achieved very easily since the Butterworth filter retains the topology of the passive filter. Therefore, we simply added a shunt capacitor across the active inductor as it is shown in Fig.5. For a cutoff frequency equal to 44KHz the capacitor values are C_1=2.02n, C_2=0.99n, C_3=2.03n and C_{AB}=0.08n. For the two examples given the simulation results are very close to the expected ones.

In both design examples, simple current mirrors have been utilized. It is know that these current mirrors have poor performance in terms of mirroring, however, with the suitable modifications they could be used to produce analog filters which are the basis for other analog circuits. Therefore, simple current-mirrors can be used as the fundamental blocks to build analog circuits using poor performance organic transistors.

V. Conclusions

A flexible way of obtaining reliable integrated CMOS active filter was presented. Low gain current modules are used along the circuit. Any type and order of filters can be designed. Simulation results of the examples given are very close to the expected ones. It is expected that the presented circuit could operate by using organic transistors. Research towards this direction is in progress.

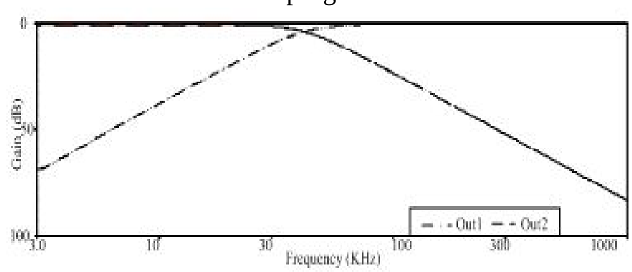

Figure 4. Low-pass and high-pass response of a Butterworth filter

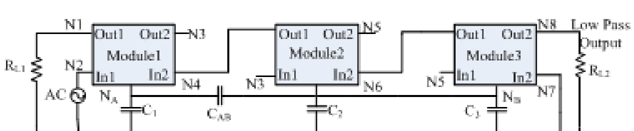

Figure 5. A Third Order Elliptical Filter

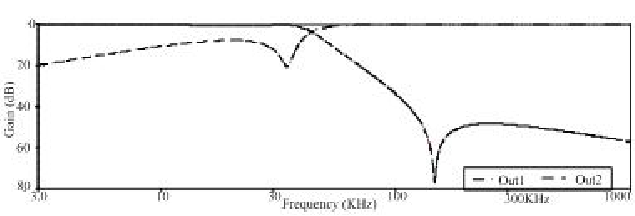

Figure 6. Complimentary low-pass and high-pass response of The Elliptical Filter

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